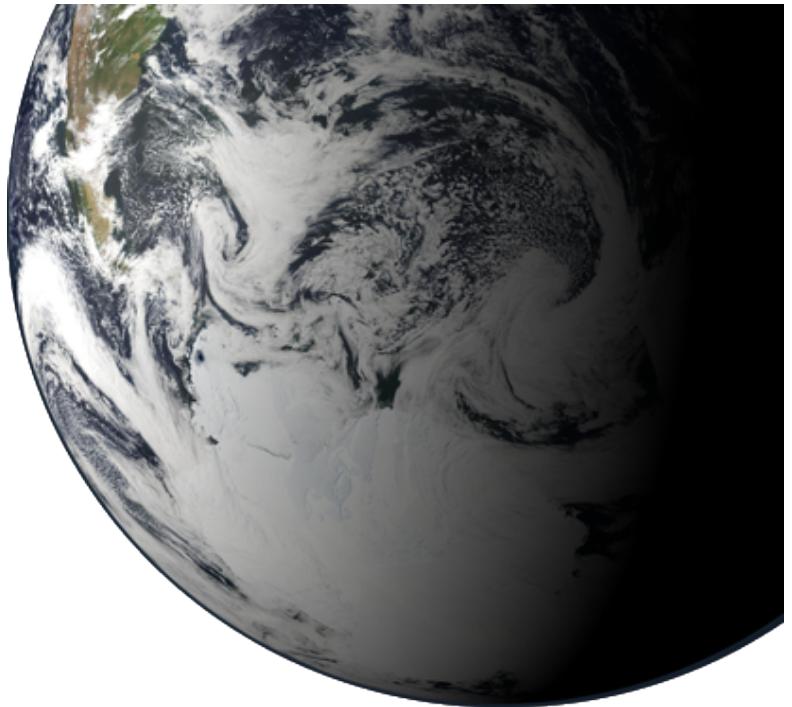


# Paleoclimate Record Points Toward Potential Rapid Climate Changes

AGU Fall Meeting  
Dec. 6, 2011



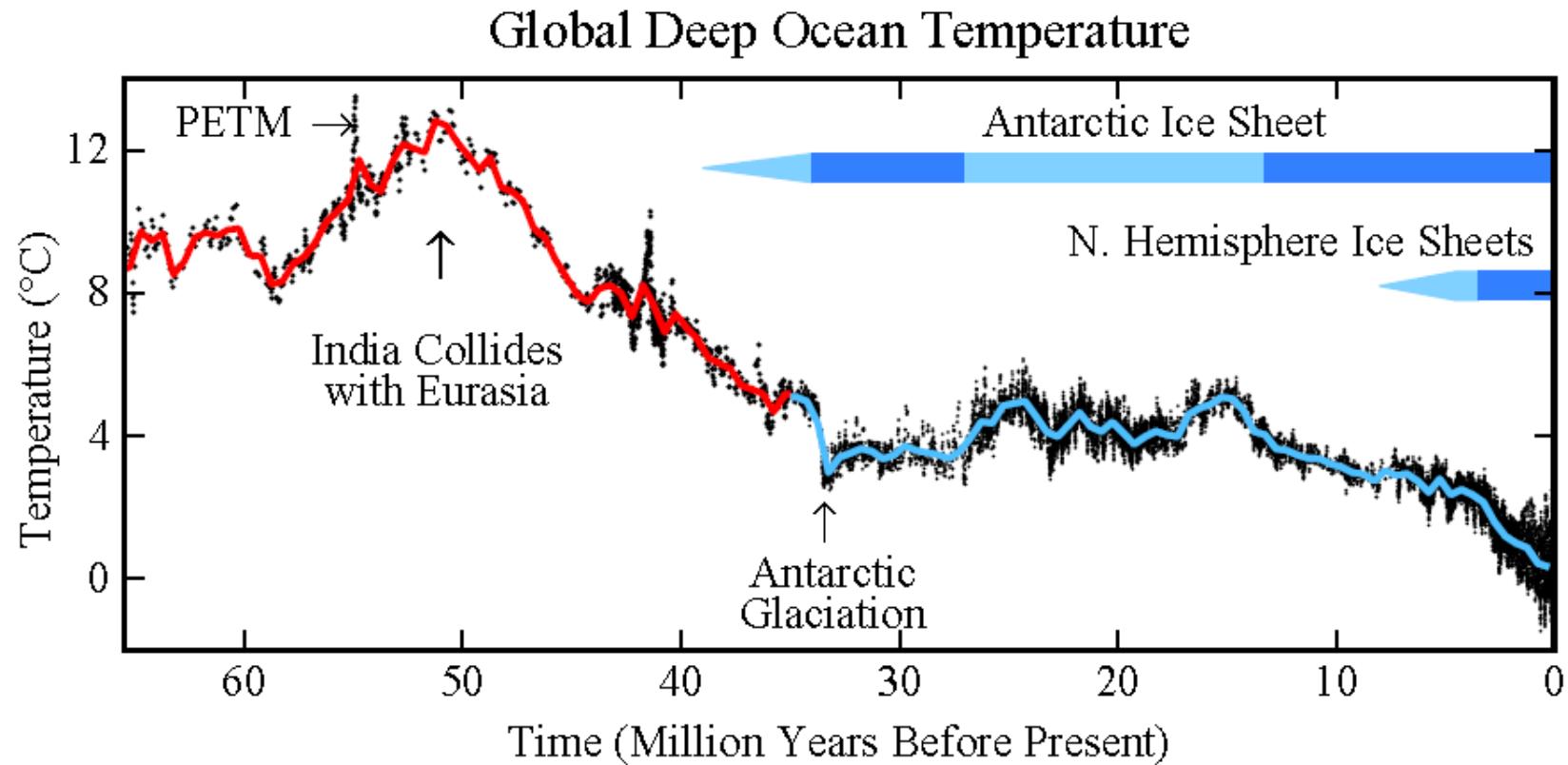
James Hansen  
Director, NASA's Goddard Institute for Space Studies, New York, New York, USA

Eelco Rohling  
Professor of Ocean and Climate Change, Southampton University, Southampton, United Kingdom

Ken Caldeira  
Senior Scientist, Department of Global Ecology Carnegie Institution of Washington, Stanford University, Stanford, California, USA



GLOBAL ECOLOGY

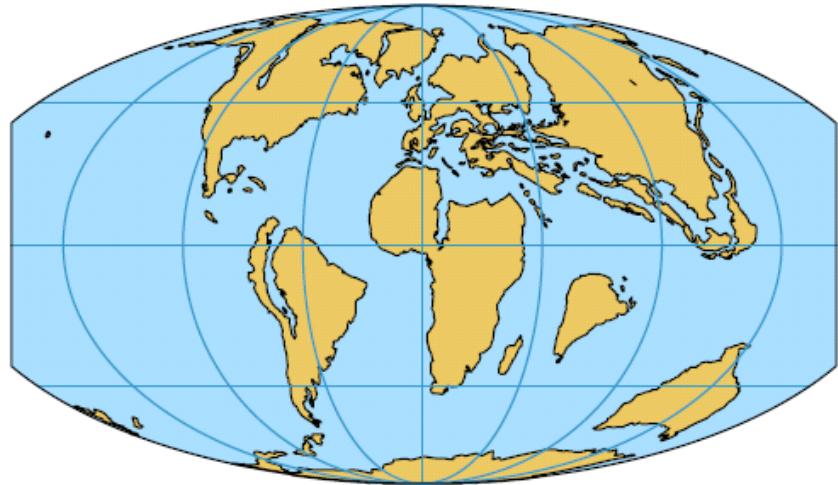


**50 million years ago (50 MYA) Earth was ice-free.**

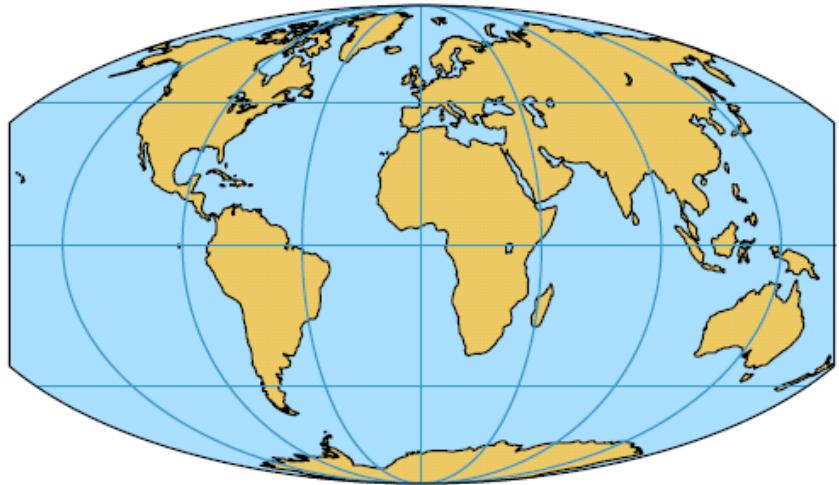
**Atmospheric CO<sub>2</sub> amount was of the order of 1000 ppm 50 MYA.**

**Atmospheric CO<sub>2</sub> imbalance due to plate tectonics  $\sim 10^{-4}$  ppm per year.**

# Cenozoic Era



End of Cretaceous (65 My BP)



Present Day

## Global Climate Forcings

External (solar irradiance): +1 W/m<sup>2</sup>

Surface (continent locations): ~1 W/m<sup>2</sup>

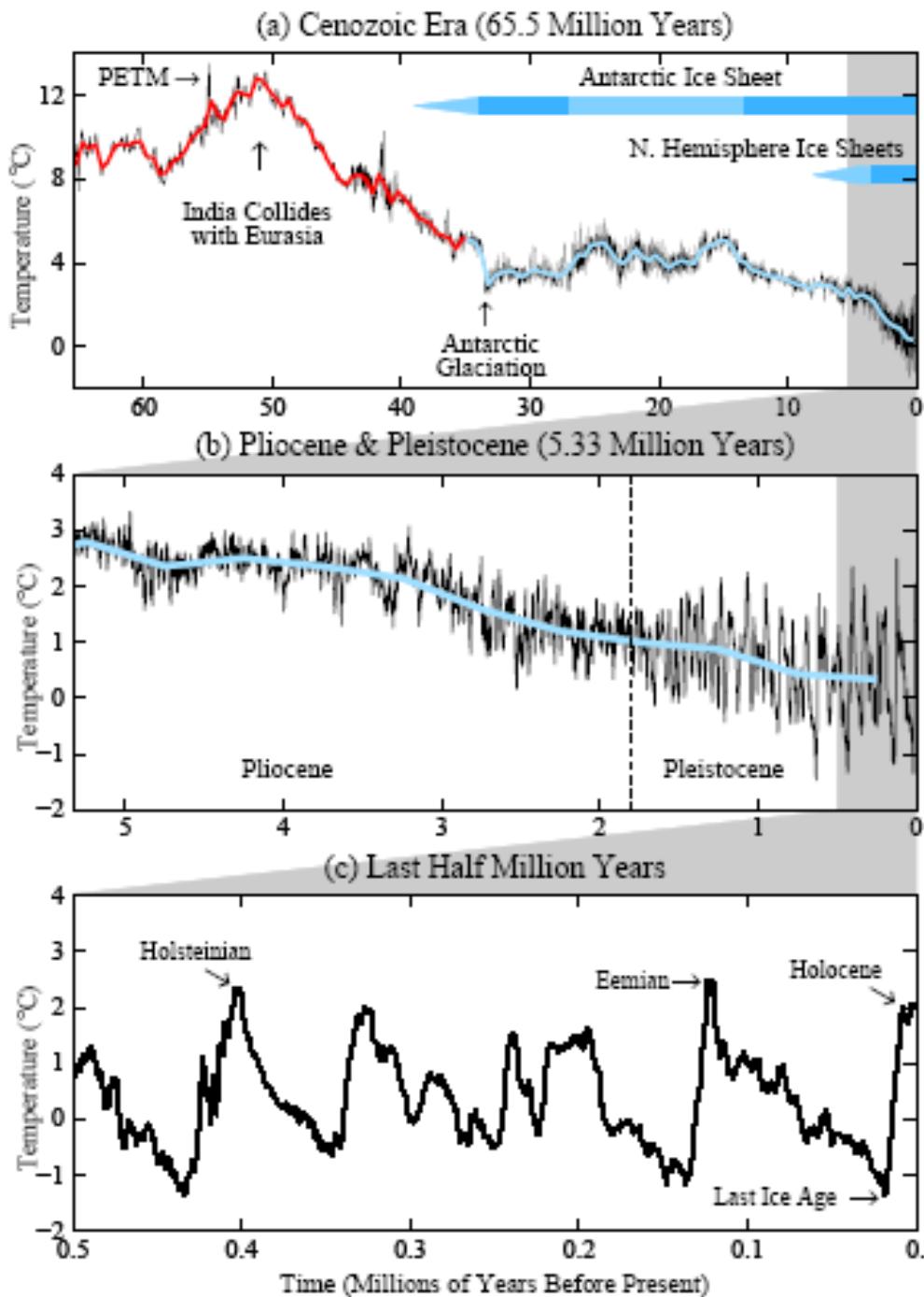
Atmosphere (CO<sub>2</sub> changes): > 10 W/m<sup>2</sup>

# Climate Change over Cenozoic Era

## 1. Dominant Forcing: Natural $\Delta\text{CO}_2$

- Rate  $\sim 100 \text{ ppm/My}$  ( $0.0001 \text{ ppm/year}$ )
- Human-made rate today:  $\sim 2 \text{ ppm/year}$

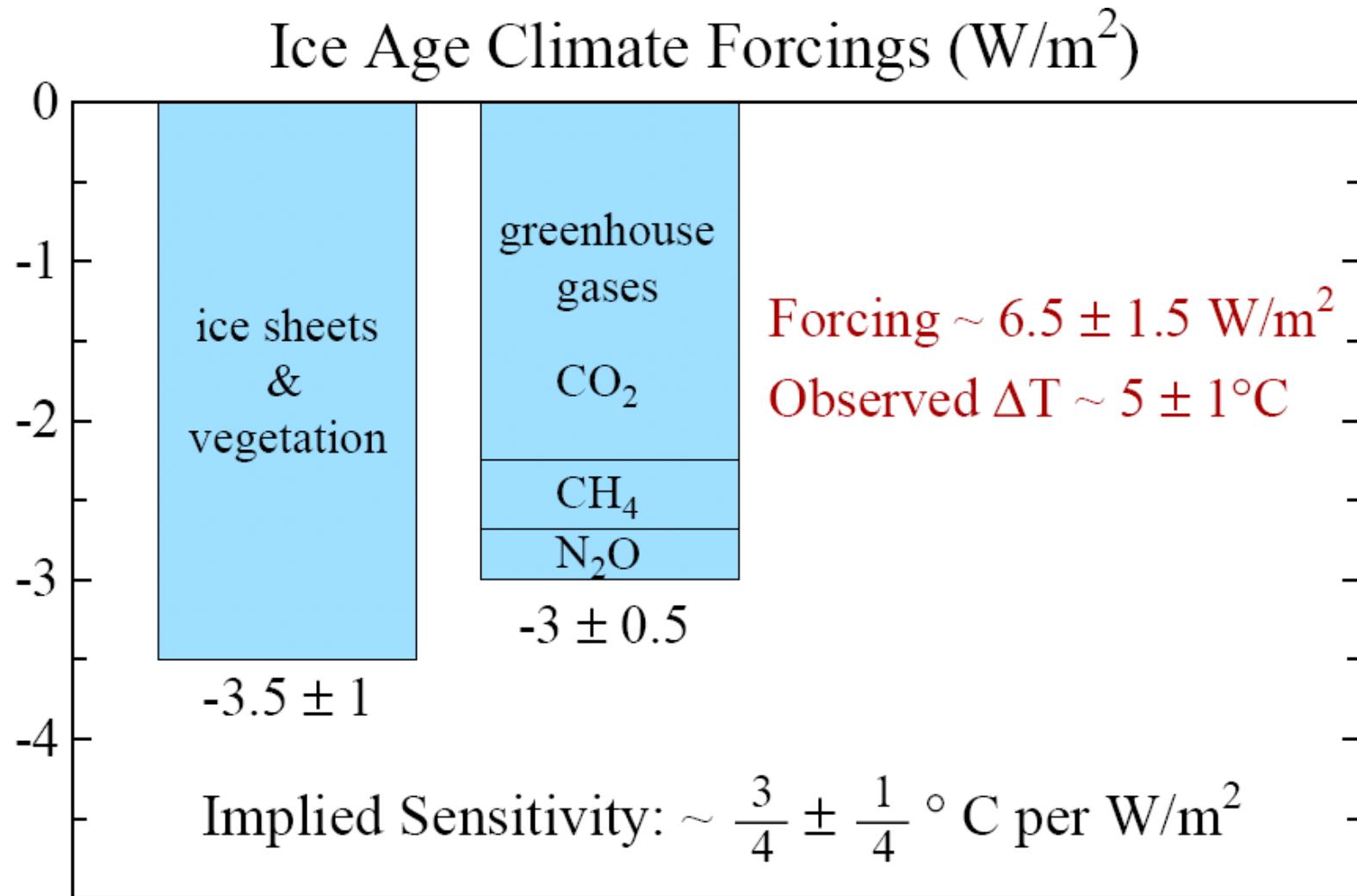
**Humans Now Overwhelm Slow Geologic Changes**



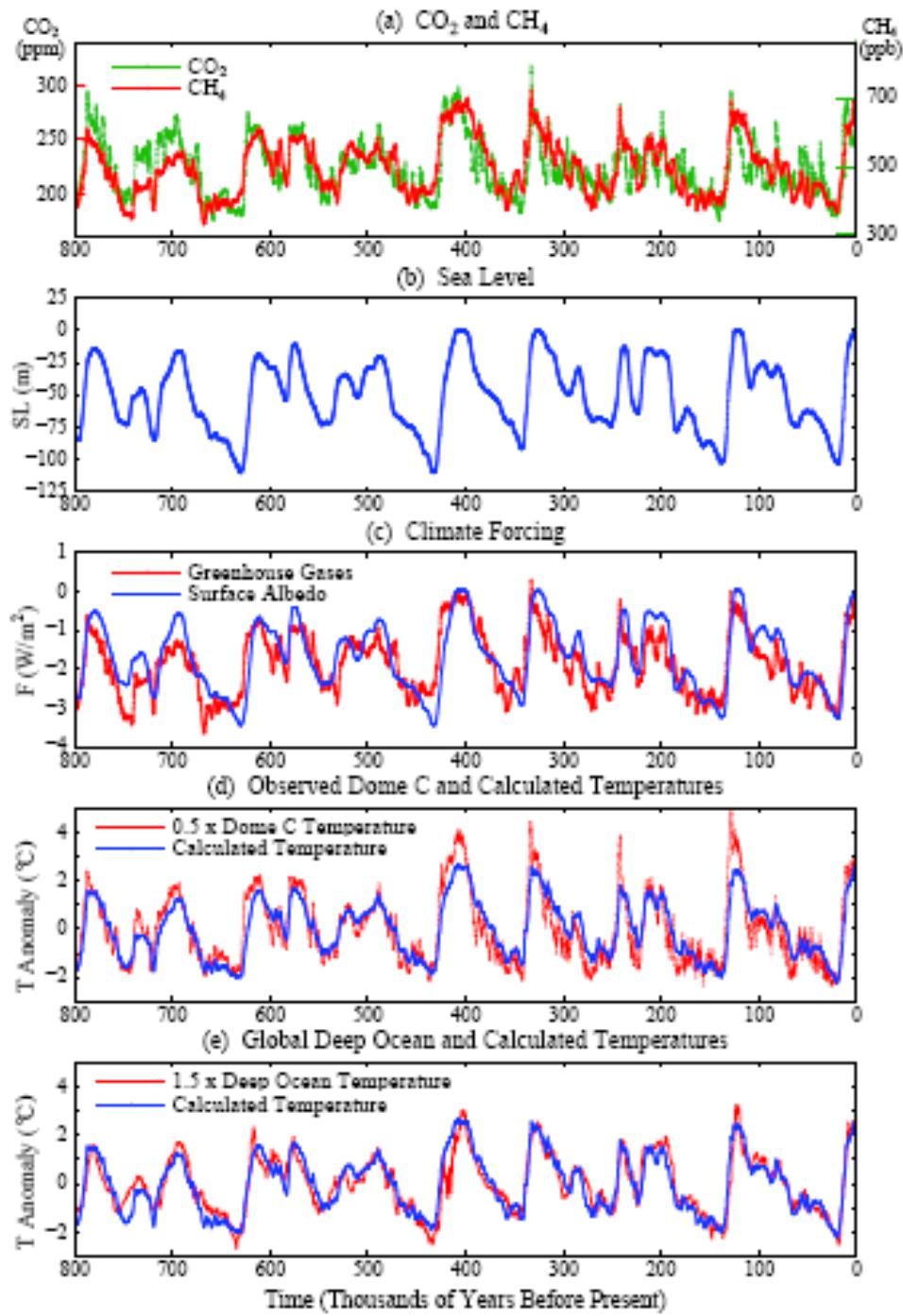
Global deep ocean temperature.

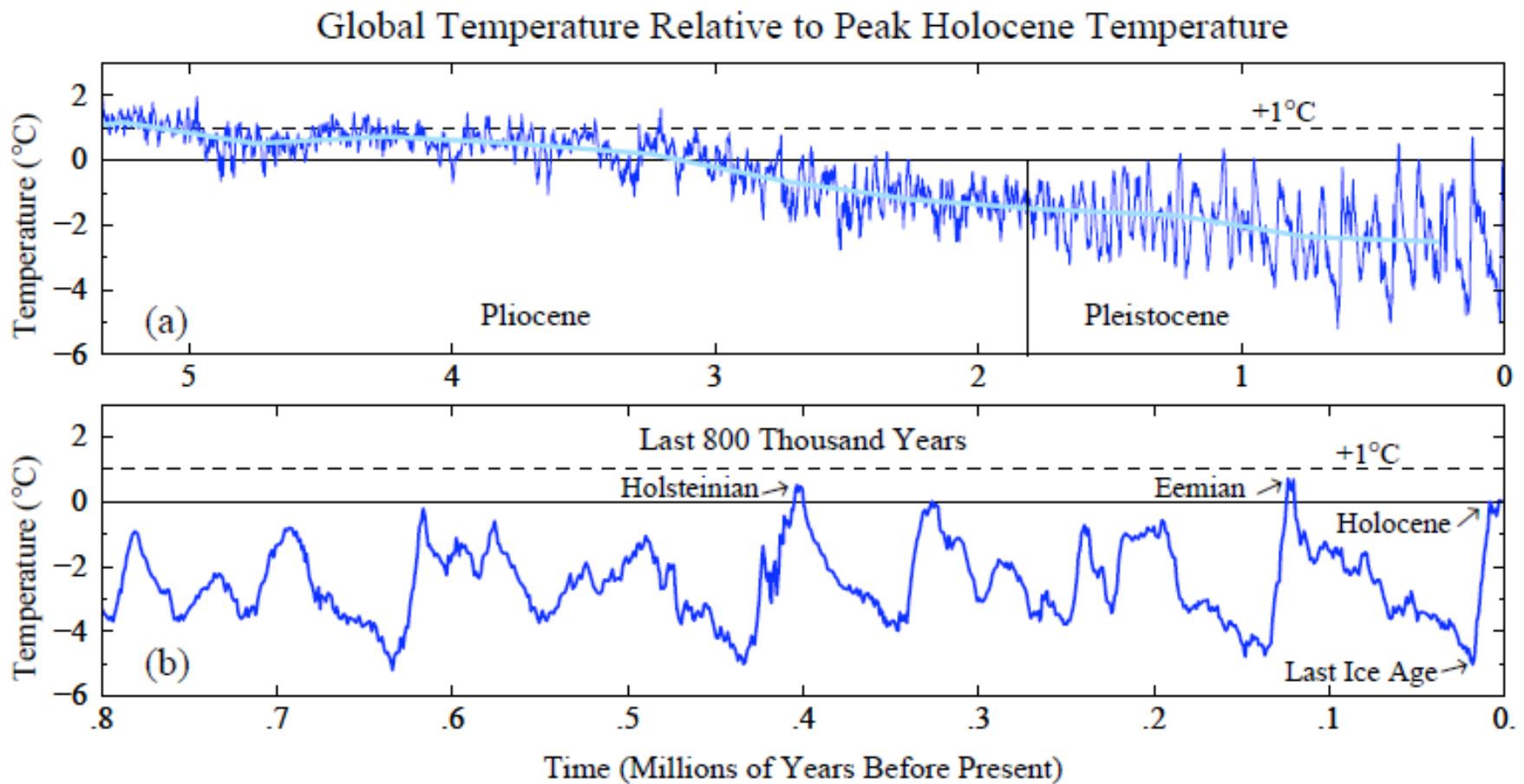
Past 5,300,000 years.

Past 500,000 years.

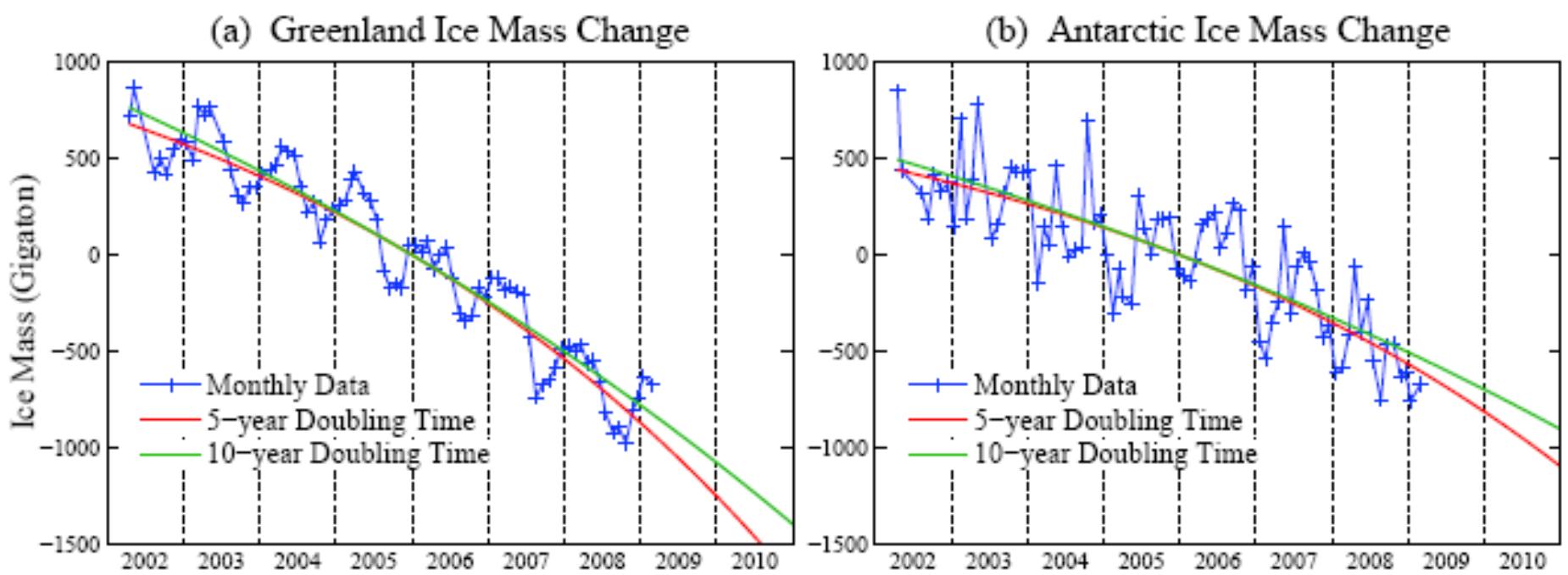


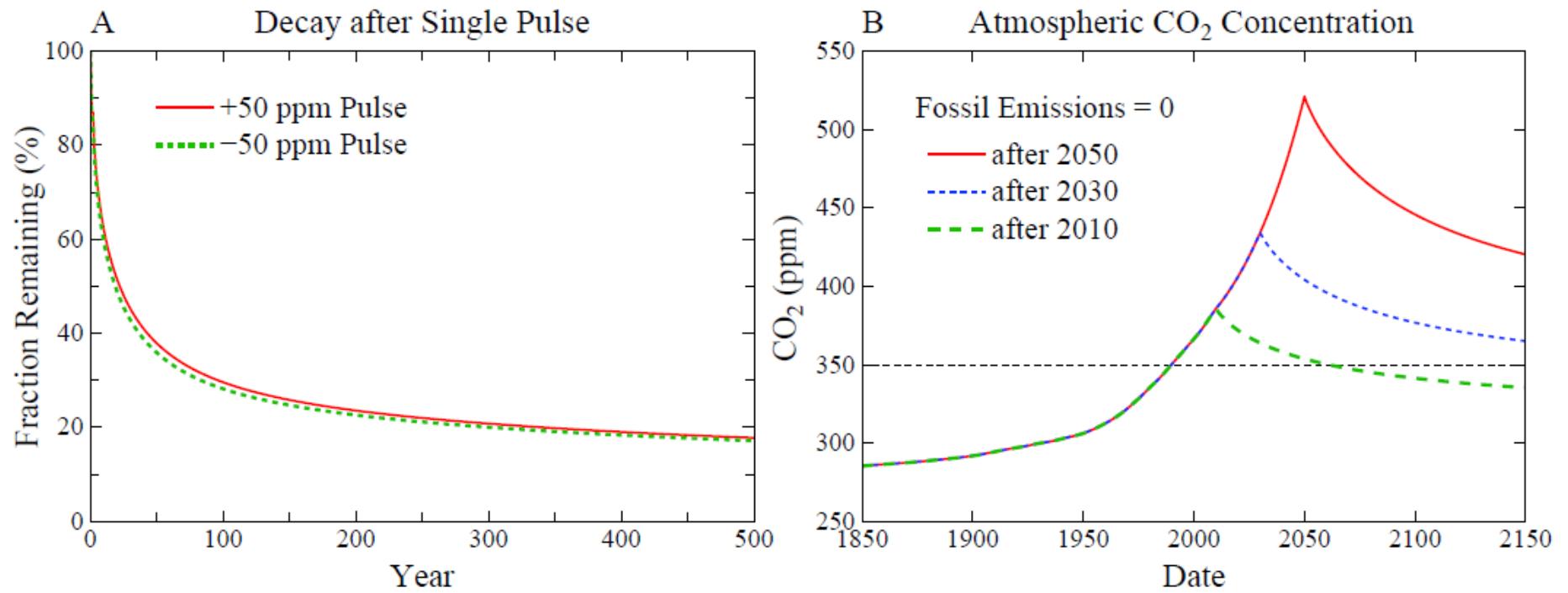
Climate forcings during ice age 20 ky BP, relative to the present (pre-industrial) interglacial period.



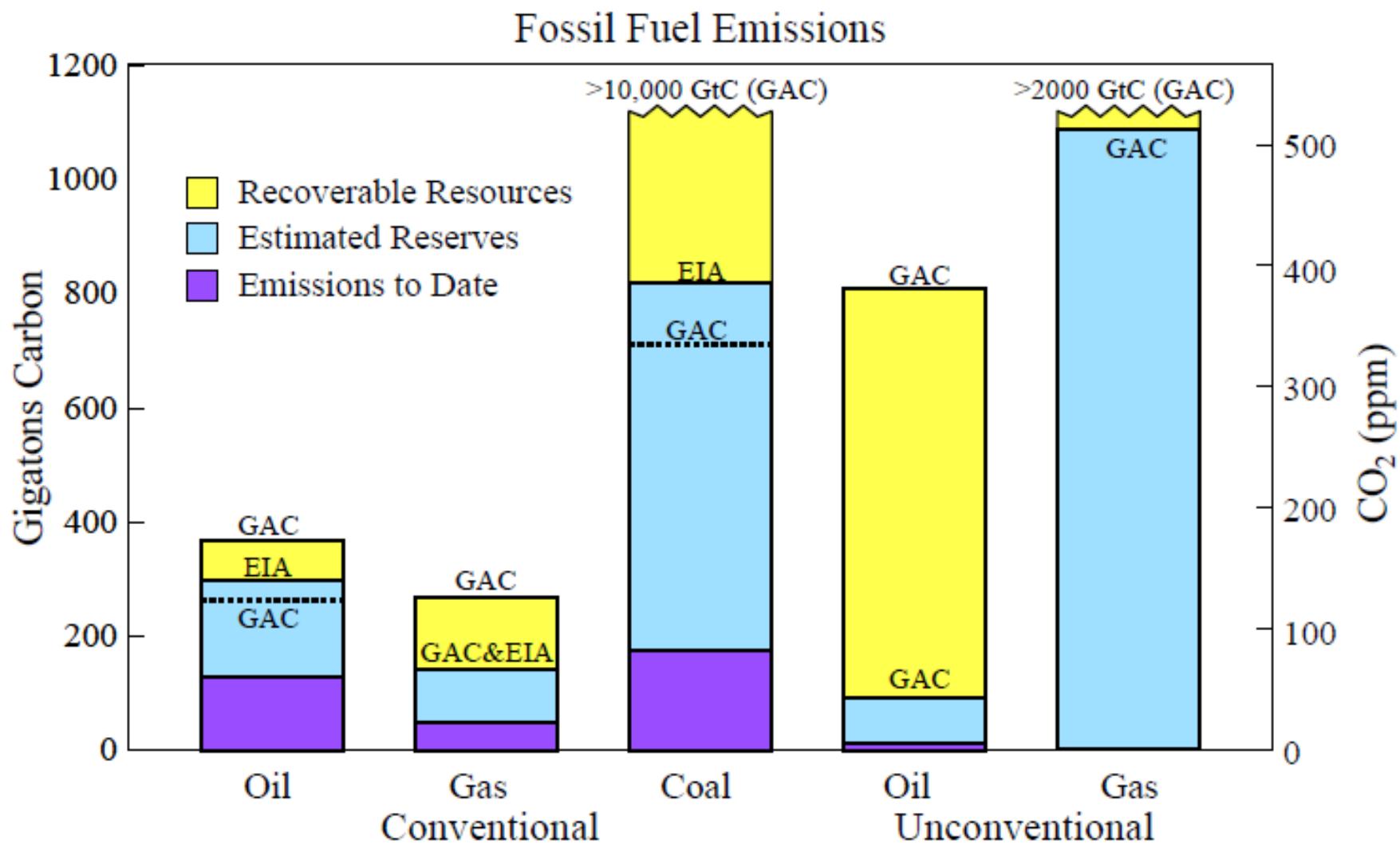


**Figure 2.** Global temperature relative to peak Holocene temperature (Hansen and Sato, 2011).





**Fig. 3.** (A) Decay of instantaneous injection or extraction of atmospheric CO<sub>2</sub>, (B) CO<sub>2</sub> amount if fossil fuel emissions are terminated at the end of 2010, 2030, or 2050.



**Fig. 6.** CO<sub>2</sub> emissions by fossil fuels (1 ppm CO<sub>2</sub> ~ 2.12 GtC). Estimated reserves and potentially recoverable resources are from EIA (2011) and GAC (2011).

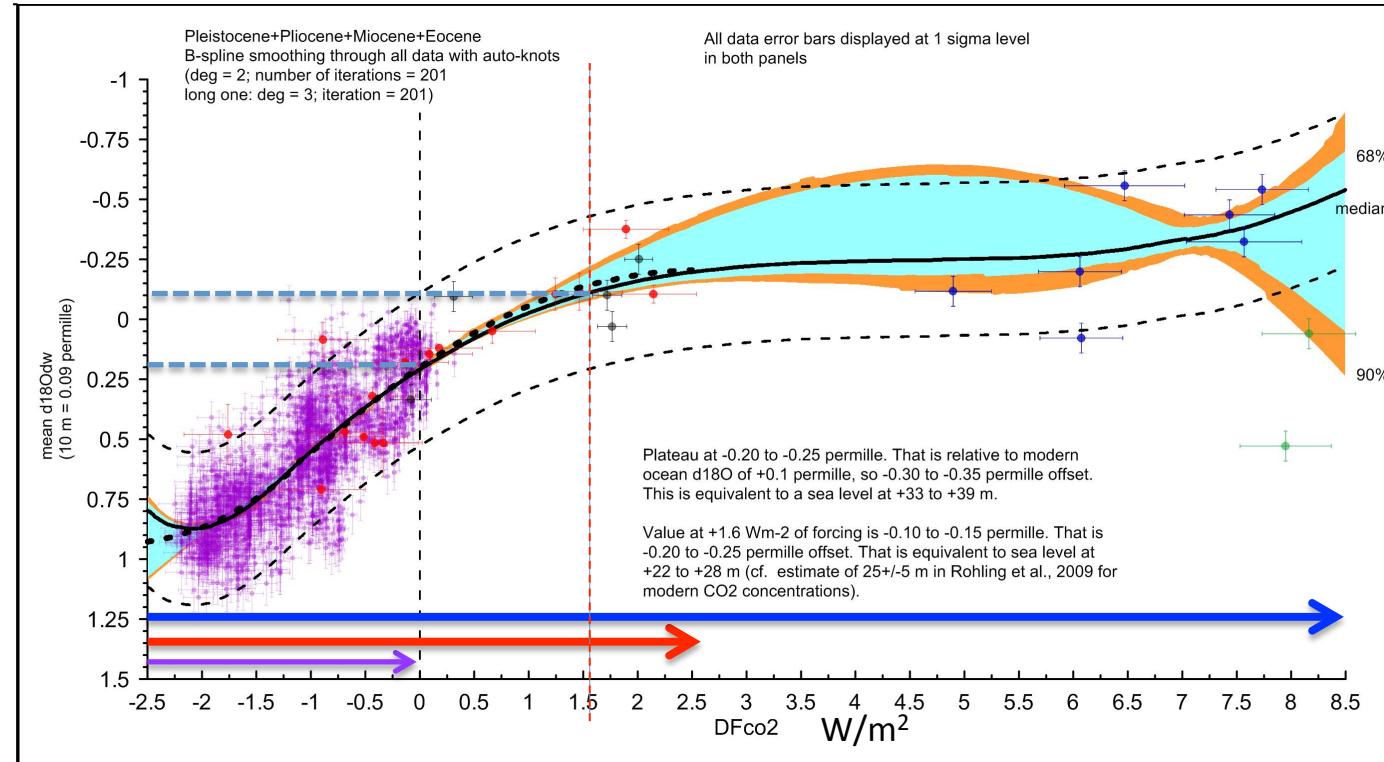
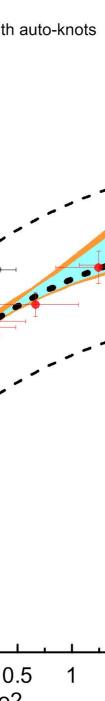
# Ice Sheet and Sea Level Response

Eelco Rohling

Professor of Ocean and Climate Change,  
Southampton University, Southampton,  
United Kingdom



# Sea level and GHG forcing – geological context



In natural context, the ‘equilibrium’ sea level for **current anthropogenic forcing** is  $25 \pm 3$ m higher than today.

This is a measure of the climate disequilibrium.

Full adjustment takes time (likely millennia)

Unpublished with  
G. Foster

Large disequilibrium creates increased likelihood of abrupt adjustments

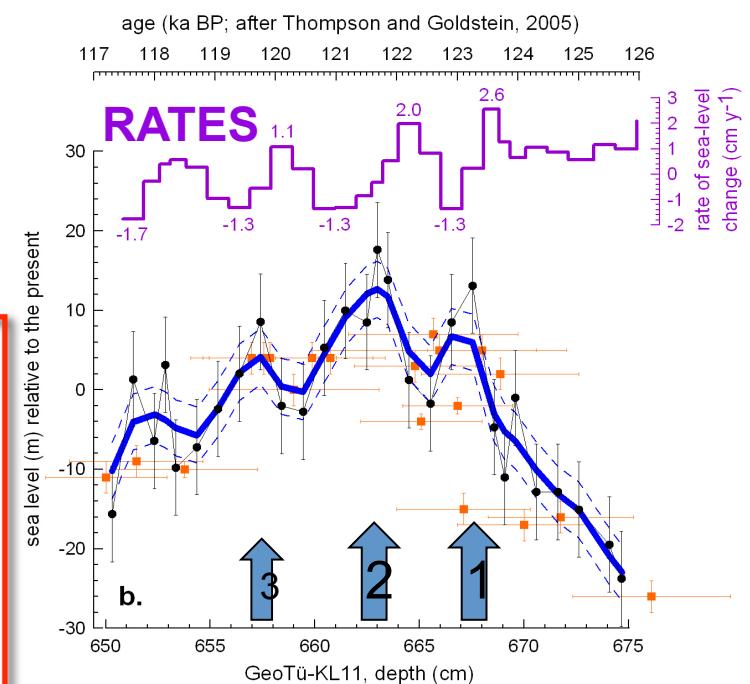
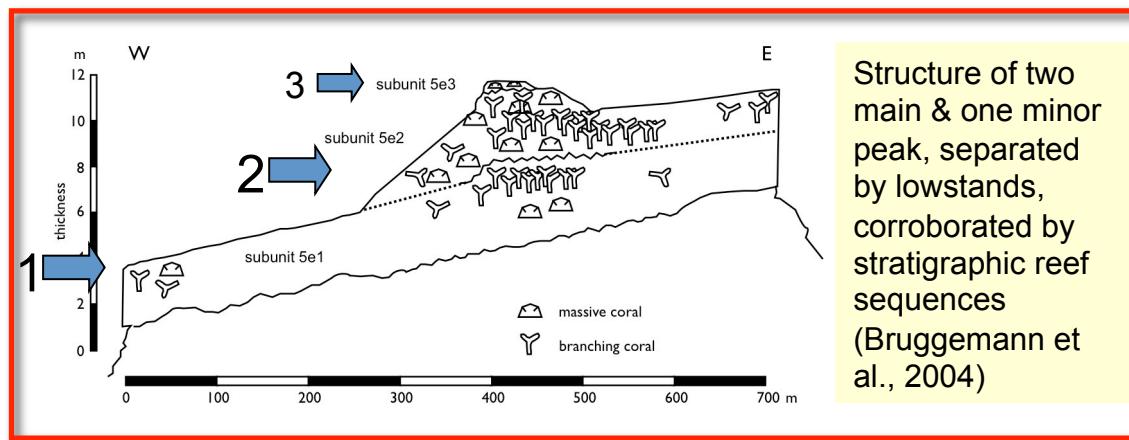
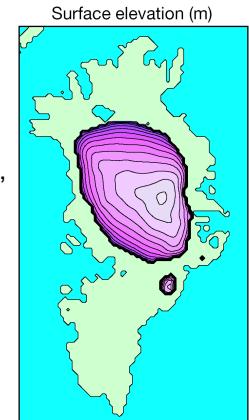
# How fast did rises occur above the present, in recent geological past?

## Last Interglacial

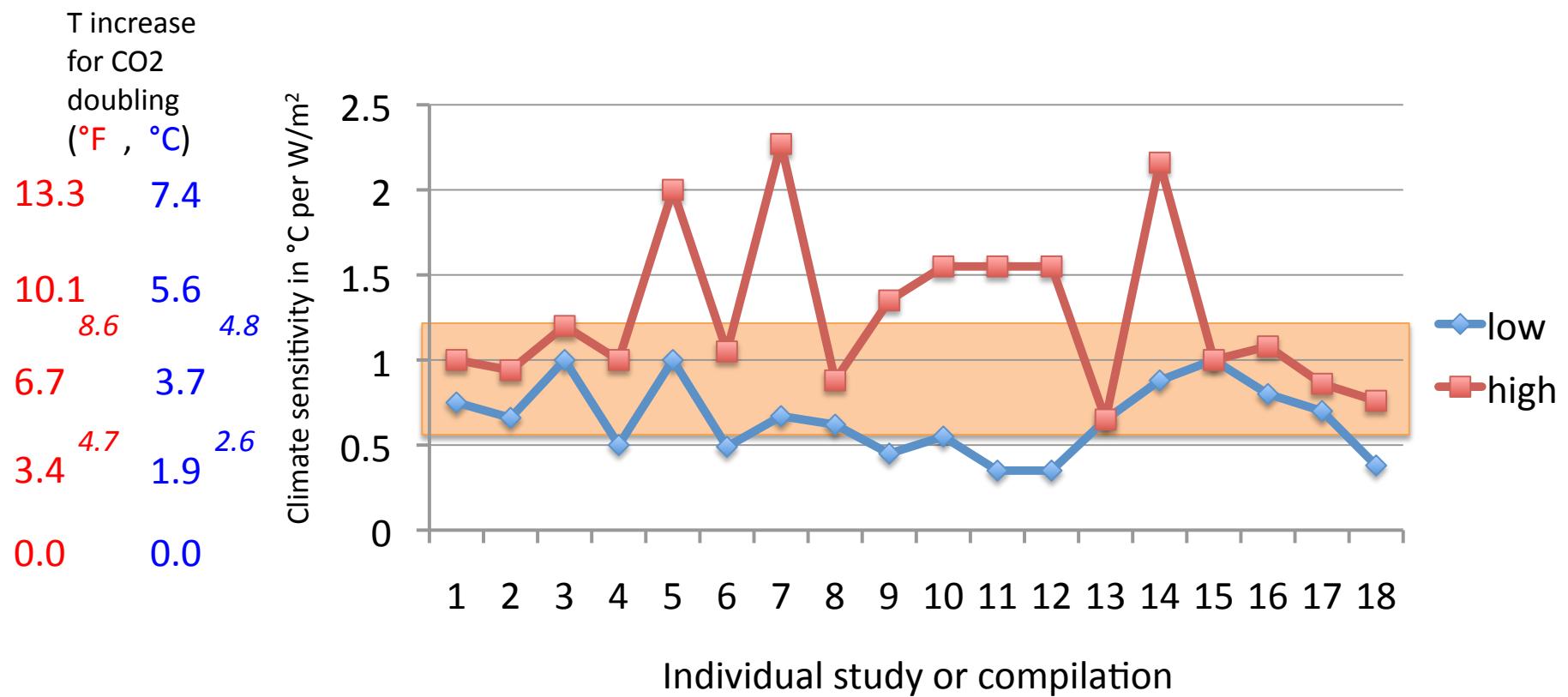
Rohling et al. *Nature Geoscience* 1, 2008

- world max. 1 °C warmer than today and Greenland up to 3-5 °C warmer
- mean sea-level highstand 4-6 m above present
- up to half due to Greenland reduction
  - but not all, so Antarctica was involved!
- we find rates of rise above 0m of **1 to 2.5 m/century**
- similar rates reported since (esp. near lower end)

A modelled “best estimate” Eemian Greenland ice sheet (Cuffey and Marshall, 2000)



## Climate sensitivity overview paper (in progress; Paleosens working group)



- Differences stem from different definitions, different reference systems, and different time-periods considered between studies.
- Schmittner et al. (Science) based on LGM is № 18.
- Rohling et al. (J. Clim in press) based on last 500,000 years is №s 9 and 10.
- Deep time warm climate values are №s 11 to 16.

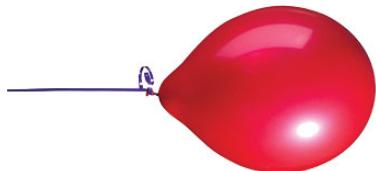
# Radiative forcing and climate response from paleoclimate to future

Ken Caldeira

6 Dec 2011

[kcaldeira@carnegie.stanford.edu](mailto:kcaldeira@carnegie.stanford.edu)

# There is no one number that is *climate sensitivity*



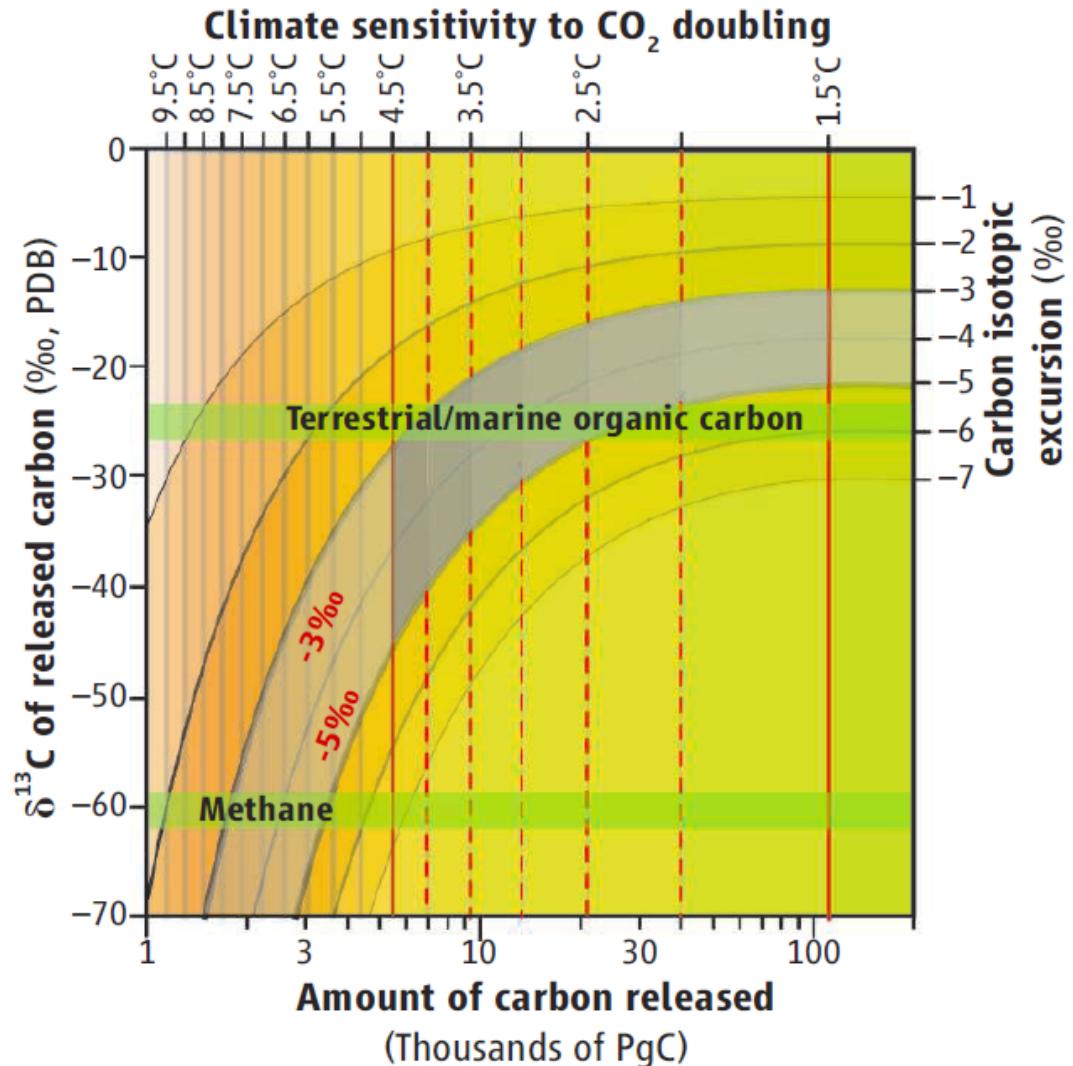
- Scientists estimate how much climate will change under conditions where some factors are allowed to vary and others are held constant.

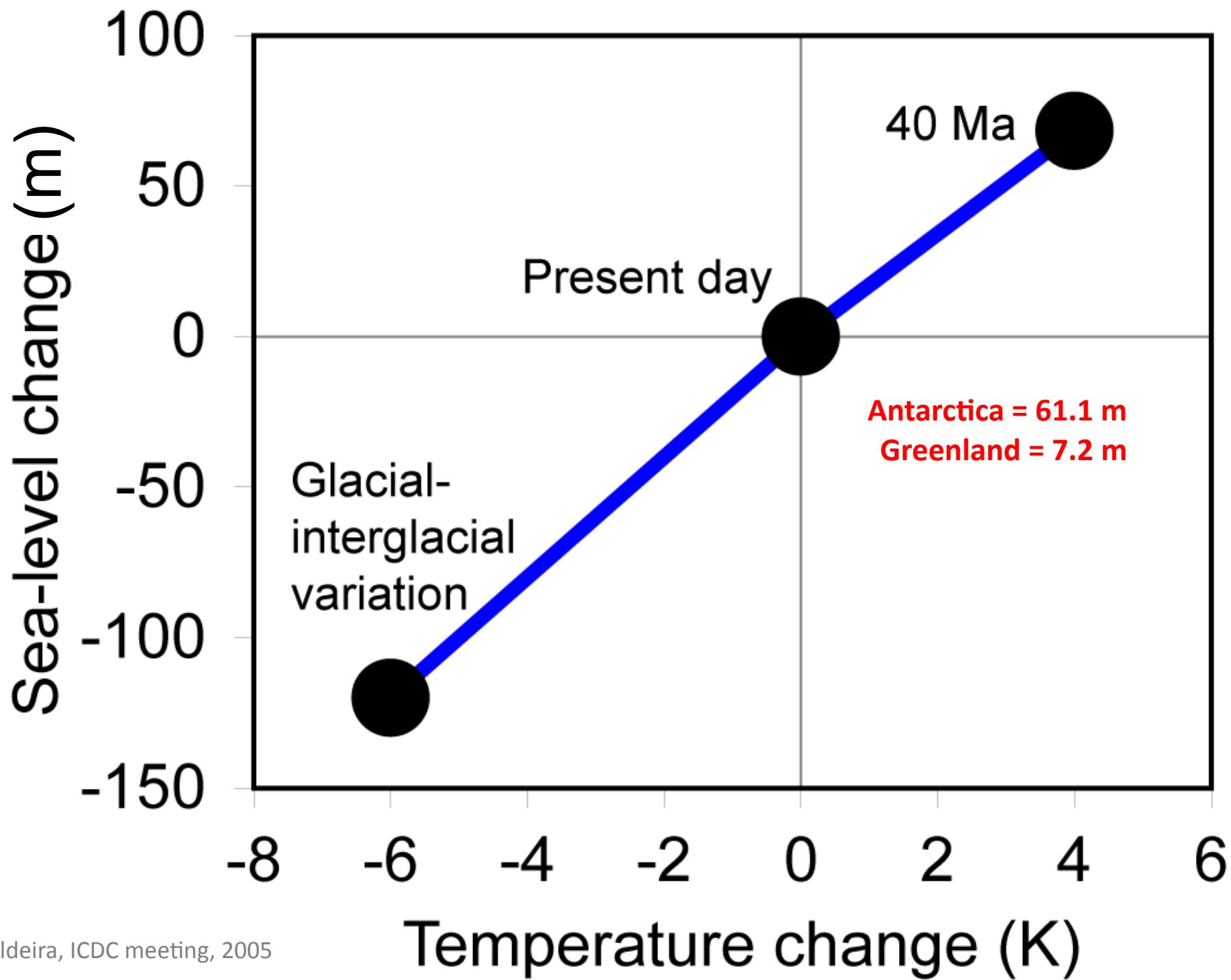
The answer depends on which factors are held constant and which vary

- Greenhouse gas concentrations
- Aerosol concentrations
- Ice sheets
- Land-cover change / Ecosystem distributions
- Atmosphere and ocean circulation
- Clouds
- Etc



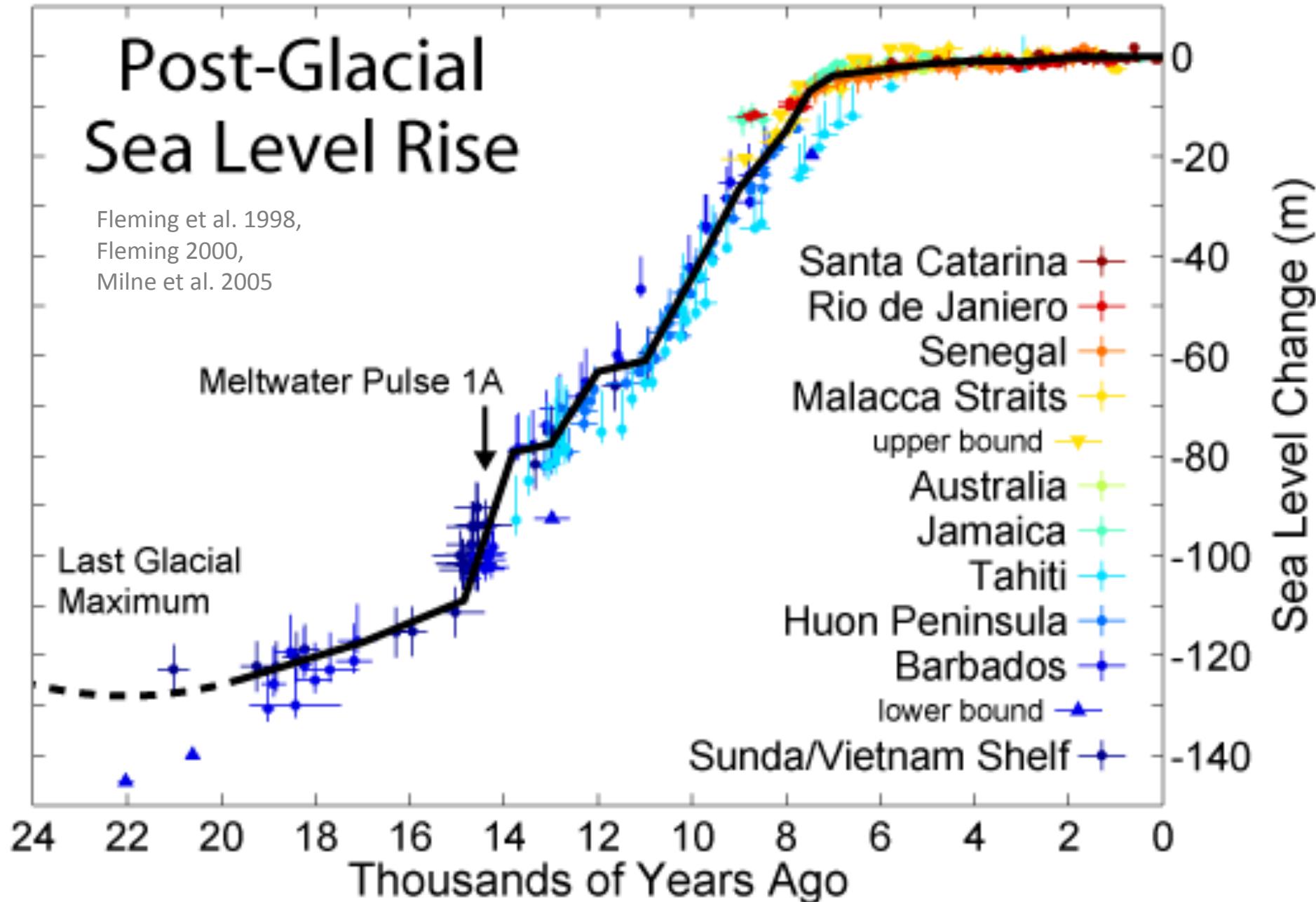
Event 55 million years ago (PETM) suggests, with long-term feedbacks,  $5.5 - 8^{\circ}\text{C}$  ( $10 - 14^{\circ}\text{F}$ ) per  $\text{CO}_2$ -doubling



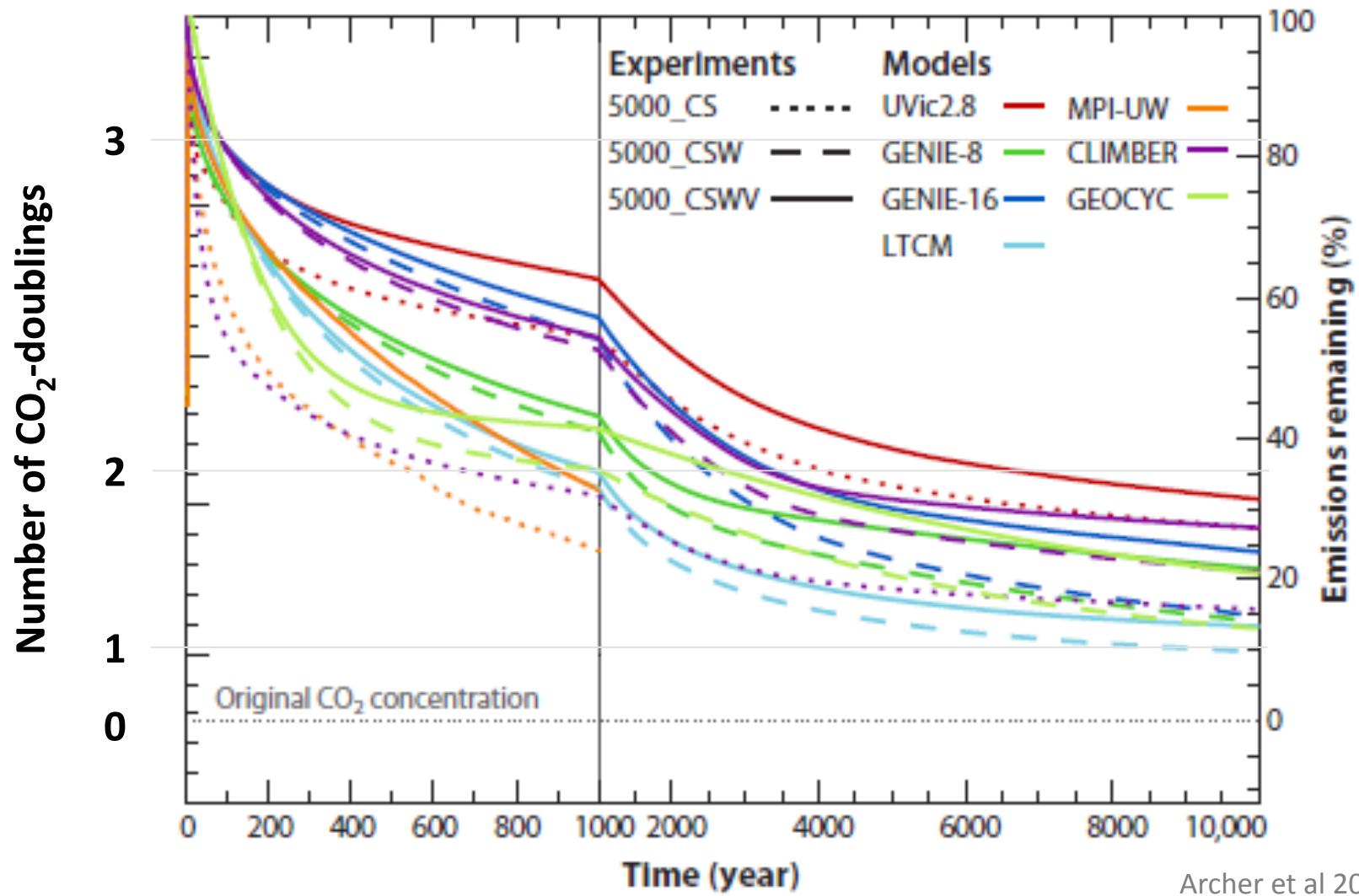


# Post-Glacial Sea Level Rise

Fleming et al. 1998,  
Fleming 2000,  
Milne et al. 2005



Climatically important amounts of carbon dioxide will remain in the atmosphere for thousands of years



Science

Morality

Facts

Values



Science

**Facts**

Morality

**Values**

**Good  
Policy**



For more information:

[http://www.giss.nasa.gov/research/briefs/hansen\\_15/](http://www.giss.nasa.gov/research/briefs/hansen_15/)

<http://pubs.giss.nasa.gov/abs/ha05510d.html>

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